
Travelling Wave Tube Amplifiers (TWTAs) for Space Applications
Travelling Wave Tube Amplifiers from Bosch – for more than 4 million operating hours in space without failure
The right connection.
BOSCH

30 years of experience enable Bosch to provide successful Travelling Wave Tube Amplifiers (TWTA) for space applications.

The rapid growth of the space communications market during the last few years demanded for TWTA of high efficieny, ultimate bandwidth of about 2 GHz including flat responses, small dimensions and low masses.

In a lot of communications satellites Bosch TWTAs have now accumulated more than 4 million operating hours in space without failure. TWTA lifetimes of up to 15 years are usual.

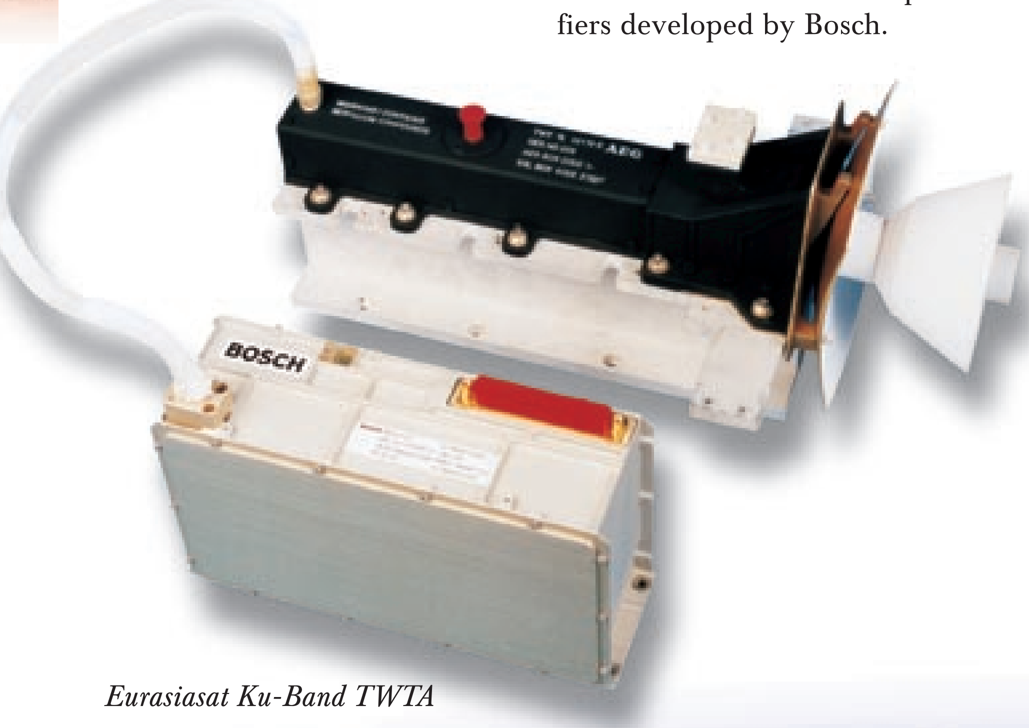
Travelling Wave Tube Amplifiers (TWTAs) for Space Applications

Bosch has provided TWTAs which satisfied requirements of NASA, ESA, Intelsat, Inmarsat, European, Asian and US commercial programs. A wide variety of applications were covered by these TWTAs. Starting from frequencies at 1.5 GHz up to the Ka-band at 30 GHz TWTAs are on hand with RF output power ranges from 10 W up to 450 W. The flexible designs of the Bosch TWTAs give reply to utmost demands in satellite bus variation, power supply requirements, automatic restart, input current limiter, helix current and other protection functions.

The Electronic Power Conditioner (EPC) of the TWTA is designed to be integrated with any Travelling Wave Tube (TWT) existing for space communications applications by converting the spacecraft bus voltages into the high voltages required for TWT operation.

A sophisticated design, qualified in various versions, flexible for any satellite bus interface such as TM/TC, main bus voltage, thermal and mechanical, enable Bosch to manufacture TWTAs for all purposes.

Even the demand for high linearized transmission requirements can be realized with Linearized Travelling Wave Tube Amplifiers (LTWTAs) using tunable linearizers and channel amplifiers developed by Bosch.



Eurasiasat Ku-Band TWTA

Description of the Travelling Wave Tube Amplifier

The TWTA is a very complex equipment and a key element of a satellite transponder. High efficiency is required in order to optimize RF output power and heat dissipation.

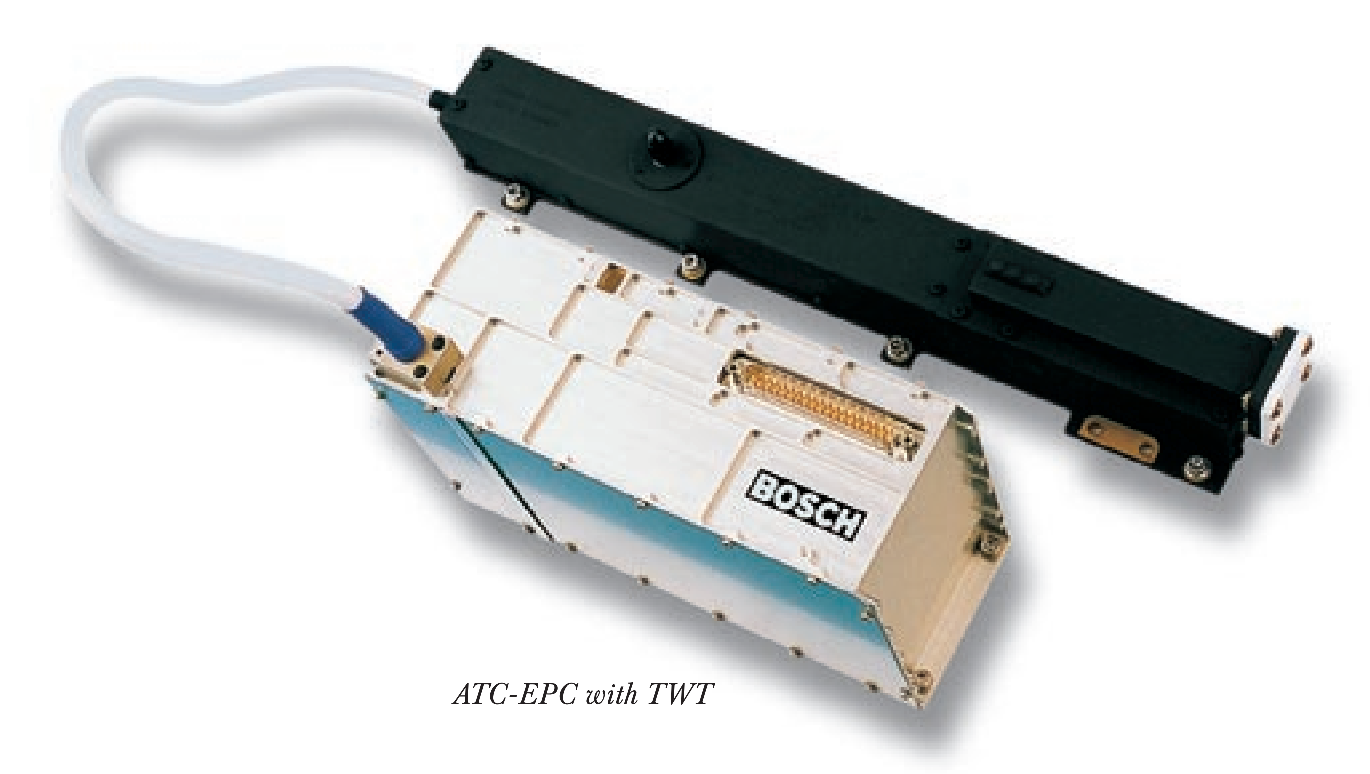
The RF performance characteristics such as high gain, gain flatness, low phase distortion and high linearity shall be combined with straight forward mechanical design which results in low mass and small dimensions.

The TWTAs consist of the Travelling Wave Tube (TWT) mainly determining the RF performance and the integrated Electronic Power Conditioner (EPC), designed and manufactured by Bosch, for power matching of the DC and bus interfaces.

The Bosch EPC is designed to be integrated with any TWT of the different TWT manufacturers by optimizing the high voltages for the individual approaches.

The integration of the TWT and EPC and the testing of the TWTA are performed by Bosch.

Based on the technology of the current TWTA programs Bosch developed a new line of EPCs for TWTAs. The family now covers the RF output power range from 10 W up to 150 W. The equipment are comprehensively qualification tested for quite a number of applications.



ATC-EPC with TWT

Interfaces and specific features

TM/TC interface

TC TWTA-ON

switches on the power supply and the TWTA is in its preheating phase. After the preheating time the high voltages for the TWT are automatically switched on and the TWTA is operational.

TC TWTA-OFF

– Status TWTA ON/OFF
– Status restart enable/disable

The following telemetries are provided:

Analogue

– Helix current
– Anode voltage
– Heater step (optional)
– Input current (optional)

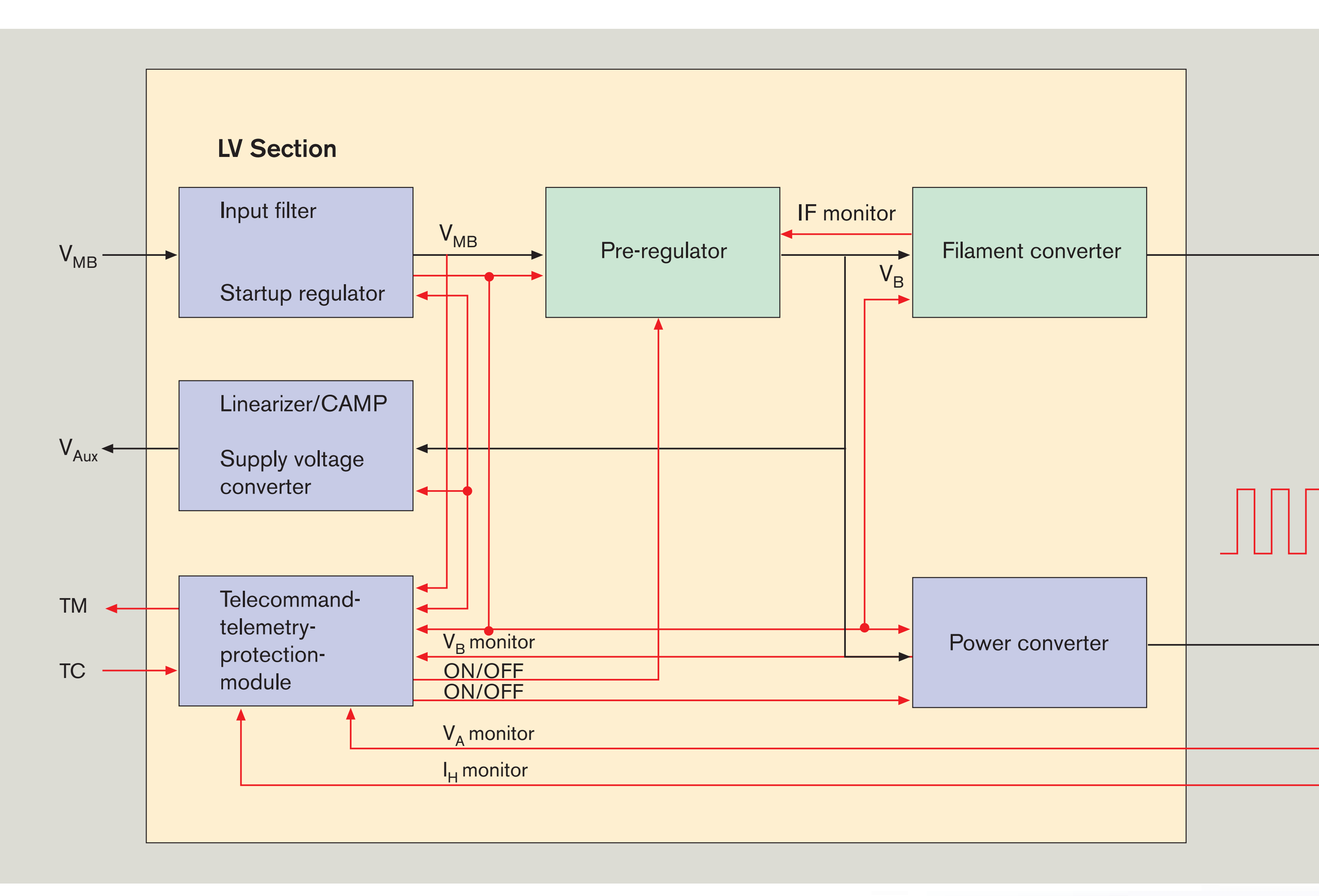
Digital

– Status TWTA ON/OFF
– Status restart enable/disable

Protections

Helix overcurrent protections

If the helix current exceeds the maximum value, the TWTA will be switched off. This protection can be disabled.



EPC Block diagram

Pre-regulator undervoltage / overvoltage protection

If the pre-regulator voltage drops below or exceeds its nominal value, the EPC is switched off.

Main bus undervoltage protection

If the main bus voltage drops below its specified range, the TWTA is switched off.

Short circuit protection

All high voltage outputs are short circuit protected.

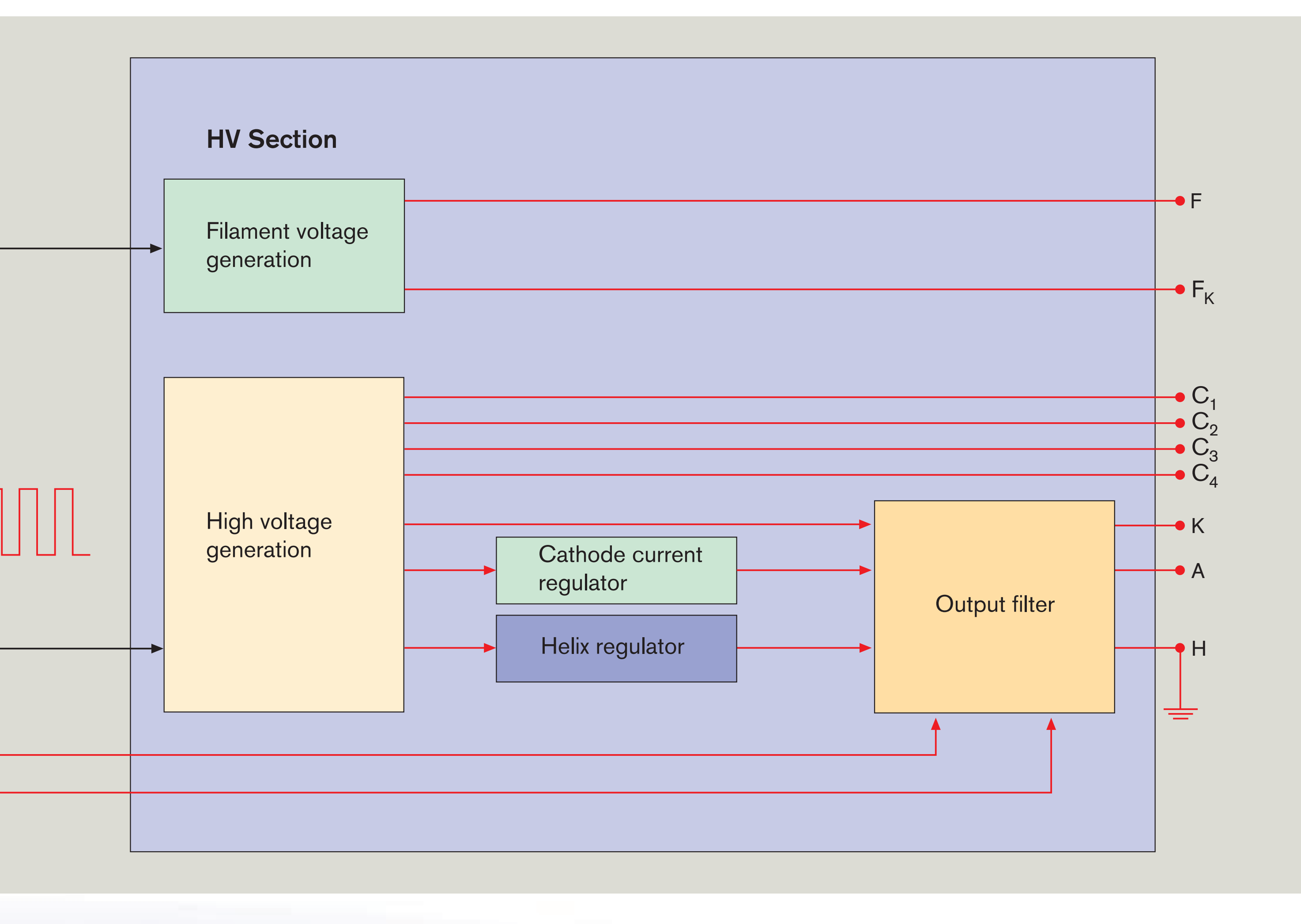
Specific features

Cathode current control loop

To eliminate any aging effect of the TWT the cathode current is kept constant. No degradation of output power will occur during lifetime. The regulation range of the anode voltage is about 10 %.

Linearizer (Lin)/ Channel Amplifier (CAMP) supply V_{Aux} (optional)

To supply a linearizer or CAMP the EPC generates up to four short circuit protected outputs.



The EPC is divided into functional blocks:

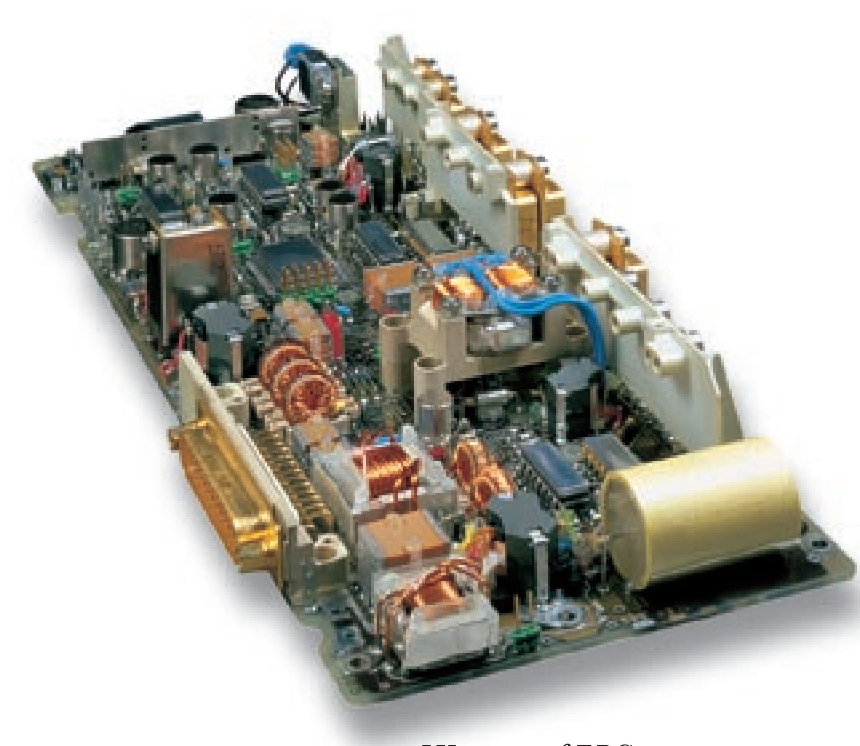
- TM/TC interface and protection circuits
- Pre-regulator
- Input filter and start-up regulator
- Power converter
- Filament converter
- Filament voltage generation
- High voltage generation
- Helix regulator
- Cathode current regulator
- Output filter

Electronic Power Conditioner

Description of Functional Modules

The basic design concept is shown on the previous page. The unregulated main bus voltage (V_{MB}) is fed via a power switch to a pre-regulator which converts the variable input voltage into a constant output voltage (V_B). The main features of the regulator are high efficiency, good conducted susceptibility behaviour, high regulator loop stability and pulse load behaviour.

An input filter suppresses voltage ripples from the main bus and switching noise from the EPC.



LV section of EPC

The constant output voltage (V_B) is directly applied to the filament converter, producing an AC voltage with square wave form for the TWT heater.

The power converter is also supplied by the constant voltage (V_B). The main features are high efficiency, suppression of high voltage transformer ringing, prevention of short circuit currents in the switching transistors and soft recovery for the high voltage diodes. This was achieved using a push-pull converter design patented by Bosch.

An important part of the power chain is the high voltage generation which is achieved by a serial high voltage concept.

The output voltage of the power converter is transformed by one high voltage transformer and rectified by stacked doubler stages for collector helix and anode voltage.

The helix voltage regulator and the cathode current regulator ensure a stable RF output power behaviour of the TWTA.

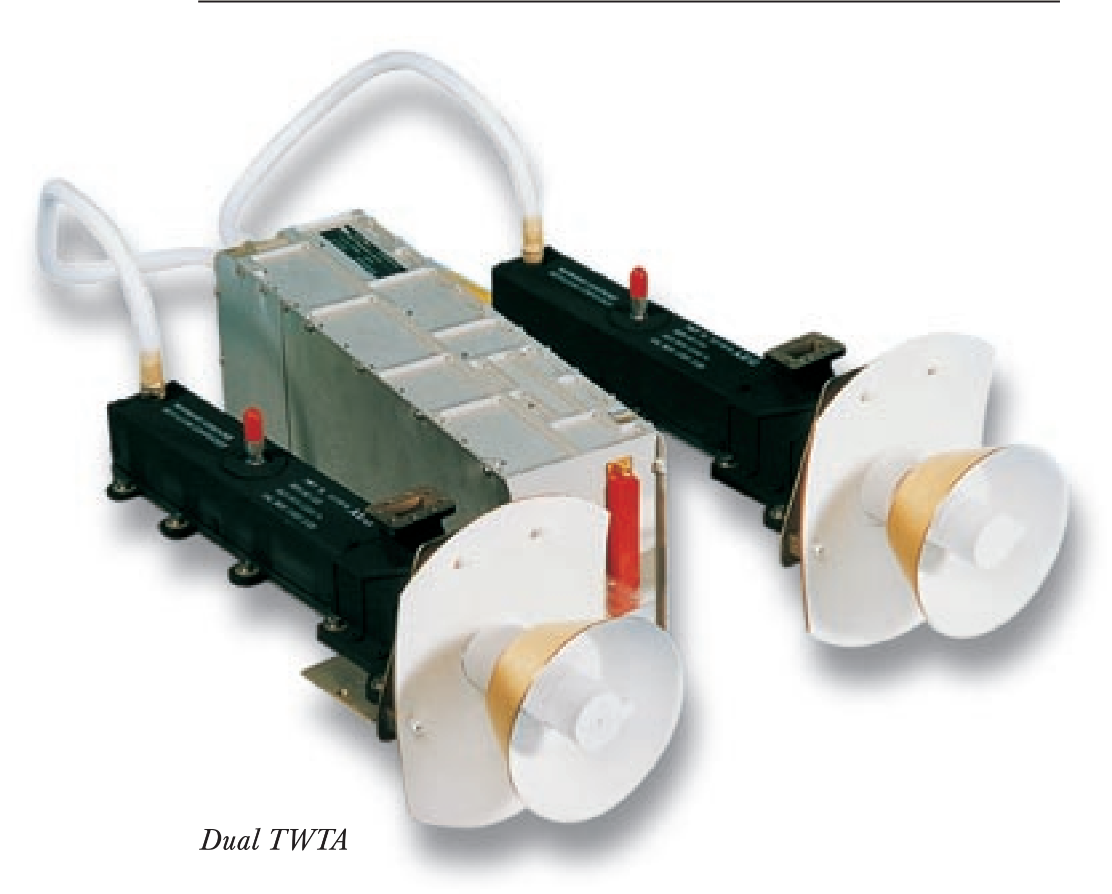
The TWTA is equipped with an automatic restart. In the case of a protection circuit is triggered, the high voltages are switched off and only the heater voltage remains applied. After a period of 200 ms the supply voltages are reapplied to the tube and the amplifier is again operational.

Dual TWTA – a cost and weight-effective solution

The dual EPC is capable to operate two 140 W TWTs simultaneously. The two TWTs can be operated as single 140 W TWTA independently or RF combined in order to provide 270 W of RF output power from radiation cooled or conducted cooled TWTs.

Key Performance Parameters

Parameter		Value
Frequency		10.70 – 12.75 GHz
Output power		120 W single
		240 W dual
Efficiency		59.5 % single
		60.6 % dual
	EPC	94 % single
	EPC	95 % dual
Input power		202 W single
		396 W dual
Mass	TWT	1100 gr
	EPC	2200 gr
Size	TWT	375 x 72 (mm)
		Ø 110 mm collector
	EPC	296 x 97 x 125 (mm)



Dual TWTA

The Microwave Power Module (MPM) is a compact amplifier consisting of Electronic Power Conditioner (EPC) with integrated Channel Amplifier (CAMP) and Linearizer (LIN).

It provides many advantages as savings in mass, mounting area and harness simplification in payload integration, as well as better EMC characteristics and limitation to a unique connection to the EPC for DC and all TC/TM functions of the MPM.

Microwave Power Module (MPM)

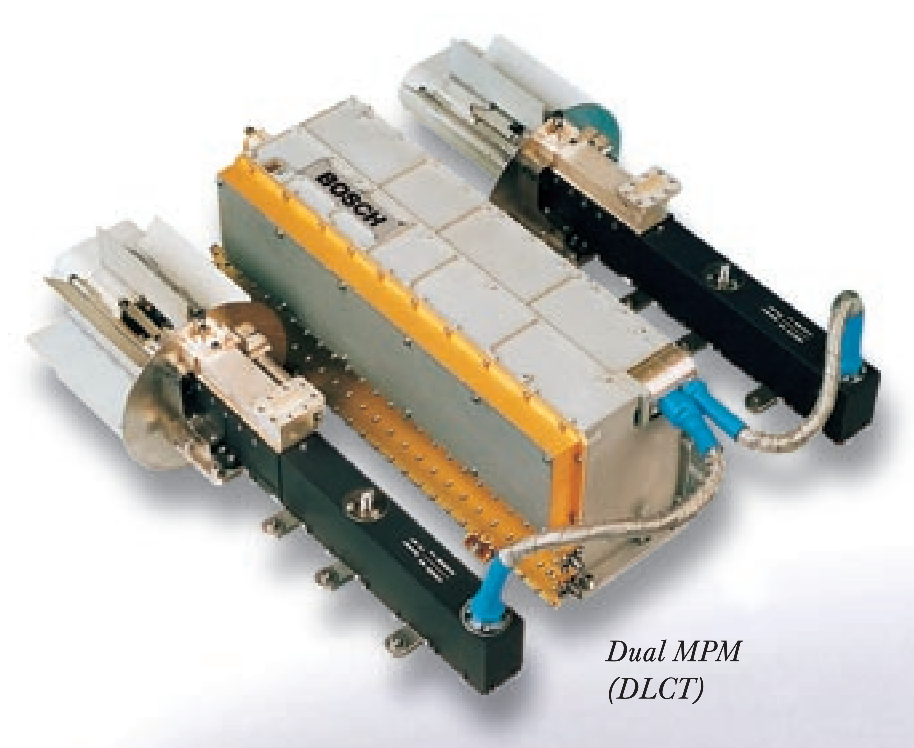
Advantages of the MPM in comparison to separate equipment

- Management reduction
  - one overall specification
  - one supplier has to be managed
- Risk reduction
  - no interface problems on repeater level (complete measurement on EQ-level)
  - no EMC problems between CAMP/LIN and EPC or TC/TM box
  - no additional margin allocation
- Mass reduction
  - no TC/TM and DC harness between CAMP/LIN and EPC or TC/TM box
- Schedule reduction
  - simplified mounting on repeater panel
  - no TC/TM and DC harness between CAMP/LIN and EPC or TC/TM box

Also available as Dual Linearized Channel TWTA (DLCT).

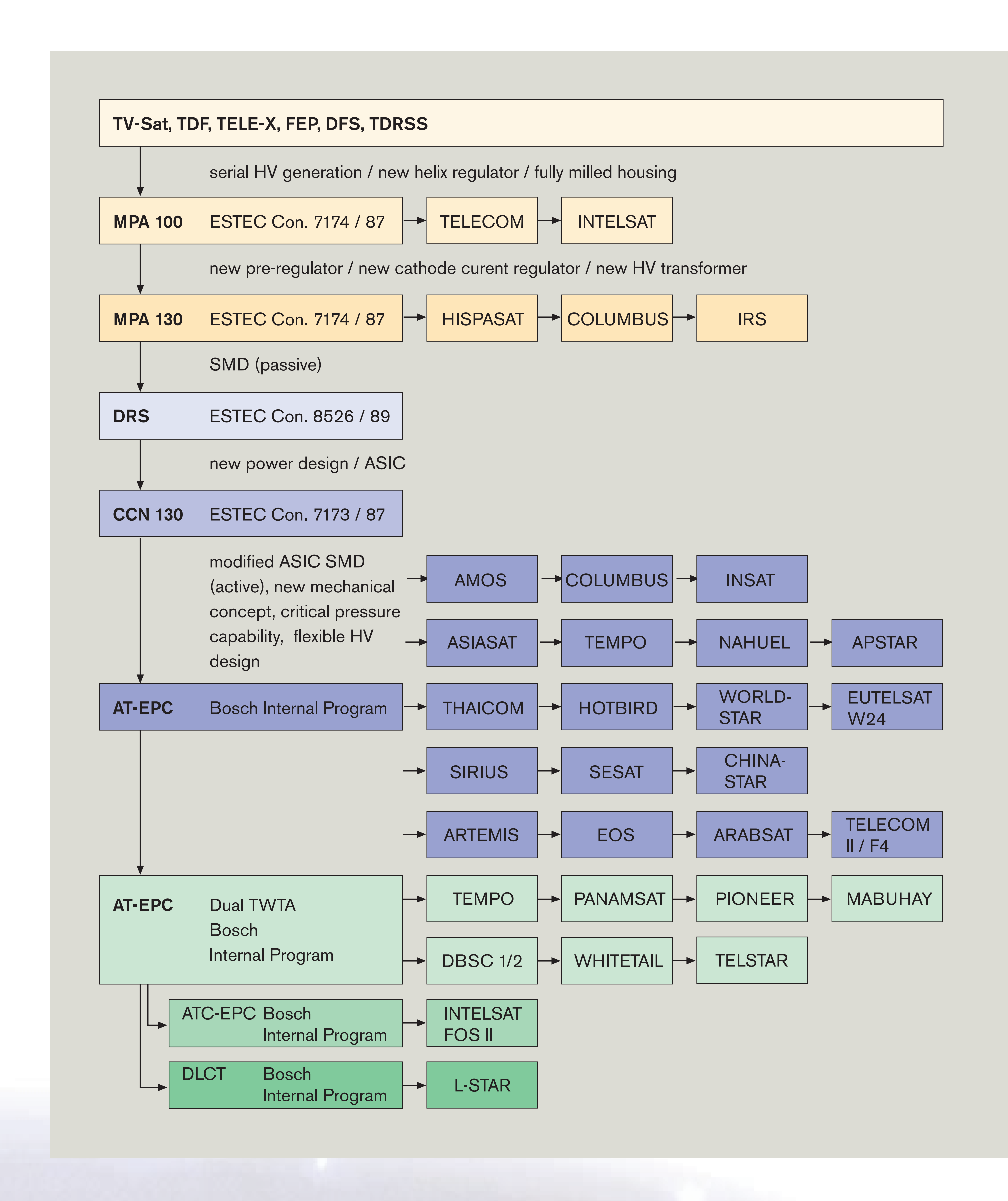
DLCT – Key Performance Parameters

$P_{out\,RF}$	2 x 113 W
$P_{in\,DC}$	< 400 W
$P_{in\,RF}$	– 58 dBm (2 x)
Dynamic range	30 dB with 1 dB/step (60 dB OPA optional)
Operation	ALC, FGM (OPA optional)
V_{MB}	100 V
Mass	2940 g (without TWT)
Dimensions	296 x 115 x 125 (mm^3) (without TWT)



Dual MPM (DLCT)

Our EPC Heritage



Our TWTA Experience

Project	Supply Voltage (Volt)	Output Power (Watt)	Frequency Range (GHz)	Mass (g) TWTA	EPC	/h (%)	Contract scope/ launch date	Remarks*
SYMPHONIE	27 ± 1 %	13	3.7 to 4.2	1670	1000		FM / 1974	
ANIK B	22.5 to 33.5	10	3.7 to 4.2	2100	1400		FM / 1978	
ANIK B	22.5 to 33.5	20	11.7 to 12.5	2190	1500		FM / 1978	
Comsat Dev.	60 ± 1 %	6/12	3.7 to 12.5	2400	1800		BB /-	Dual-mode TWTA
Nat. Programme	50 ± 2 %	20	10.95 to 11.7	2240	1600		BB /-	RC
COMSAT	50 + 2 % / −3 %	230	11.7 to 12.5	12000	8500		EM /-	Eclipse test of TWT, RC
Nat. Programme	50 + 2 % / −3 %	450	11.7 to 12.5	15000	10000		EM /-	
UNISAT	42 ± 2 %	230	11.7 to 12.5	12000	7500	/ 89 %	EM /-	CCR, RC
TDRSS 1-6	22 to 43	30	11.7 to 14.05	3350	2650	/ 78 %	FM / 1983	
FEP	20 to 60	22	20.2 to 21.2	3600	2400	/ 79 %	FM / 1986	CCR and HS
INMARSAT	50 +2 % / −3 %	358	1.5375	20500	8500		EM /-	Linear. TWTA, CCR, RC
TV-SAT 1	50 +2 % / −3 %	230	11.7 to 12.5	12000	8500	/ 89 %	FM / 1988	CCR and ARU, RC
TDF-1	50 +2 % / −3 %	260	11.7 to 12.5	12000	8500	/ 89 %	FM / 1988	CCR and ARU, RC
TELE-X	50 +2 % / −3 %	230	11.7 to 12.5	12000	8500	/ 89 %	FM / 1989	CCR and ARU, RC
TV-SAT2	50 ± 2 %	230	11.7 to 12.5	12000	7500	/ 89 %	FM / 1989	CCR and ARU, RC
TDF-2	50 ± 2 %	260	11.7 to 12.5	12000	7500	/ 89 %	FM / 1989	CCR and ARU, RC
DFS	26 to 43	20	11.45 to 11.7	2750	1850	/ 81 %	FM / 1989	CCR
DFS	26 to 43	20	12.5 to 12.75	2750	1850	/ 81 %	FM / 1989	CCR
DFS	26 to 43	20	19.7 to 20.1	3000	1950	/ 82 %	FM / 1989	CCR
ECS	50 ± 2 %	20	10.95 to 11.7	2750	1850		FM / 1988	CCR
Nat. Programme	27 to 43	37	10.95 to 12.75	3000	2100	/ 85 %	EM /-	CCR
Nat. Programme	27 to 43	60	10.95 to 12.75	3200	2300	/ 86 %	EM /-	CCR
EUTELSAT II	27 to 43	50	10.95 to 12.75	3500	2450	/ 86 %	FM / 1990	CCR and HS
110 W TWTA	42 +1 % / −2 %	110	11.7 to 12.75	3800	2450	/ 90 %	EMQ /-	CCR and HS, prequalif.
130 W TWTA	26.5 to 42.5	130	11.7 to 12.75	5000	2700	/ 91 %	EMQ /-	CCR, ARU and HS, RC
TDRS 7	22 to 43	32	13.40 to 14.05	3300	2200	/ 86 %	FM / 1990	CCR
Telecom II	26 to 43	55	12.5 to 12.75	–	2400	/ 87 %	FM / 1991	CCR, ARU, SPS
Intelsat VII	26 to 43	35/50	10.9 to 12.75	3270	2400	/ 88 %	FM / 1992	CCR, ARU, HS, SPS
Hispasat	26 to 43	55	11.45 to 12.75	3500	2400	/ 87 %	FM / 1992	CCR, ARU, SPS
Hispasat	26 to 43	40	7	3500	2400	/ 86 %	FM / 1992	CCR, ARU,
Hispasat	26 to 43	110	11.45 to 12.75	4000	2650	/ 90 %	FM / 1992	CCR, ARU, SPS
IRS	28 to 42	40	8	–	2650	/ 87 %	FM / 1993	CPO
COMETS	35 to 50	30	23	–	2200	/ 86 %	FM / 1995	
COLUMBUS PPF	21.5 to 35.5	53	27	3000	1650	/ 88 %	FM / 1997	CCR, ARU
COLUMBUS PPF	22 to 35.5	27	8	3300	2300	/ 86 %	FM / 1997	CCR
EUTELSAT II/F6	27 to 43	75	12	3300	2550	/ 90 %	FM / 1995	CCR, ARU
AMOS	25 to 41.5	35	12	2600	1600	/ 89 %	FM / 1995	CCR, ARU, SPS, CPO
ASIASAT	100 ± 3	115	12	2550	1600	/ 93 %	FM / 1995	CCR, ARU, HS, SPS
ARTEMIS	42 ± 1	35	23	2440	1600	/ 91 %	FM / 1997	CCR, ARU
ARTEMIS	42 ± 1	30	20	2500	1600	/ 91 %	FM / 1997	CCR, ARU
INSAT	26.5 to 42.5	55	6	–	1600	/ 90 %	FM / 1995	CCR, ARU
EOS	24 to 32	20	14	2500	1600	/ 88 %	FM / 1998	CCR, ARU
TEMPO	100 ± 3	2 x 113	12	4800	2400	/ 93 %	FM / 1995	CCR, ARU, SPS, RC, DT
ARABSAT	42 ± 1	93	12	–	1600	/ 93 %	FM / 1996	CCR, ARU, SPS
Telecom II/F4	26 to 42	55	12	–	1600	/ 90 %	FM / 1996	CCR, ARU, SPS
Telecom II/F4	26 to 42	40	6	–	1600	/ 89 %	FM / 1996	CCR, ARU, SPS
MGS	24 to 32	25	8	–	1600	/ 88 %	FM / 1996	CCR, ARU
Turksat F3	26 to 42	55	12	2400	1600	/ 90 %	FM / 1996	CCR, ARU, SPS

Project	Supply Voltage (Volt)	Output Power (Watt)	Frequency Range (GHz)	Mass (g) TWTA	EPC	/h (%)	Contract scope/ launch date	Remarks*
Hotbird Plus	26 to 42	110	12	2650	1800	/93 %	FM/1996	CCR, ARU, SPS
Hotbird 3	26 to 42	110	12	2650	1800	/93 %	FM/1997	CCR, ARU, SPS
PanAmSat 6	100 ± 3	2 x (80–100)	12	4800	2400	/93 %	FM/1997	CCR, ARU, SPS, RC, DT
PanAmSat 6	100 ± 3	35	12	2400	1600	/89 %	FM/1997	CCR, ARU
Nahuel	26 to 42	55	12	2400	1600	/90 %	FM/1997	CCR, ARU, SPS
Mabuhay 1/2	100 ± 3	2 x 115	12	4400	2300	/93 %	FM/1997	CCR, ARU, SPS, RC, DT
Telstar	100 ± 3	2 x 100	12	4700	2300	/93 %	FM/1997	CCR, ARU, SPS, RC, DT
APSTAR	100 ± 3	2 x 113	12	4400	2300	/93 %	FM/1996	CCR, ARU, SPS, RC, DT
APSTAR	100 ± 3	60	4	2450	1600	/92 %	FM/1996	CCR, ARU, SPS
Thaicom	42 ± 1	97	12	2450	1600	/93 %	FM/1997	CCR, ARU, SPS
DBSC1	70	2 x 120	12	4400	2300	/93 %	FM/1998	CCR, ARU, SPS, RC, DT
CHINASTAR	70	135 R	12	2750	1800	/93 %	FM/1998	CCR, ARU, SPS, RC
Hotbird 4/5	26 to 42	135	12	2650	1800	/93 %	FM/1998	CCR, ARU, SPS
SIRIUS 1/2	50 ± 2	88/52	12	2450	1600	/93 %	FM/1998	CCR, ARU, SPS
PIONEER 1	100	2 x 110	12	4400	2300	/93 %	FM/1998	CCR, ARU, SPS, RC, DT
PIONEER 2	100	2 x 125	12	4400	2300	/93 %	FM/1998	CCR, ARU, SPS, RC, DT
Eutelsat III	50	90/100	12	2400	1600	/93 %	FM/1998	CCR, ARU, SPS
PanAmSat 7	100	2 x 107	12	4400	2300	/93 %	FM/1997	CCR, ARU, SPS, RC, DT
PanAmSat 8	100	2 x 107	12	4400	2300	/93 %	FM/1998	CCR, ARU, SPS, RC, DT
Whitetail 1	70	2 x 120	12	4400	2300	/93 %	FM/1998	CCR, ARU, SPS, RC, DT
Whitetail 2	70	135 R	12	2750	1800	/93 %	FM/1998	CCR, ARU, SPS, RC
Sesat	35 to 42	95	12	2450	1600	/93 %	FM/1998	CCR, ARU, SPS
Worldstar	26 to 42	150	1.6	3800	1800	/93 %	FM/1998	CCR, ARU, SPS
L-STAR	100	2 x 113	12	5000	2200	/93 %	FM/1998	MPM
USSB	70	2 x 100	12	4400	2300	/93 %	FM/1999	CCR, ARU, SPS, DT
TELSTAR 7	100	2 x 120	12	4400	2300	/93 %	FM/1999	CCR, ARU, SPS, RC, DT
Echostar 4	70	2 x 120 R	12	4400	2300	/93 %	FM/1999	CCR, ARU, SPS, RC, DT
Intelsat K-TV	26 to 42	110	12	2650	1800	/93 %	FM/1999	CCR, ARU, SPS, RC, DT
ARABSAT 2 BSS	50	140	12	2450	1600	/93 %	FM/1999	CCR, ARU, SPS
ASTRA 2B	26 to 42	110	12	2650	1800	/93 %	FM/1999	CCR, ARU, SPS
Intelsat 9	100	100 R	12	2350	1400	/93 %	FM/1999	CCR, ARU, SPS
Intelsat 9	100	45–65	4	2150	1350	/93 %	FM/1999	CCR, ARU, SPS
Koreasat 3	70	85	20.5	2400	1600	/93 %	FM/1999	CCR, ARU, SPS
Hispasat 1C	26 to 42	110	12	2650	1800	/93 %	FM/1999	
Chinasat	100	2 x 120	12	4400	2300	/94 %	FM/1999	CCR, ARU, SPS, DT, RC
EOS 2	22 to 40	25	8	2400	1600	/90 %	FM/1999	CCR, ARU
Astra 1K Ka-band	50	63	20	2200	1350	/93 %	FM/2000	CCR, ARU, SPS
Astra 1K Ku-band	50	105	12	2200	1350	/93 %	FM/2000	CCR, ARU, SPS, RC
Eurasiasat Ku-band	50	106	12	2200	1350	/93 %	FM/2000	CCR, ARU, SPS, RC
Eurasiasat X-band	50	114	7.5	3000	1600	/93 %	FM/2000	CCR, ARU, SPS, RC
AMRC	100	216	2.3	3450	1630	/94 %	FM/2000	CCR, ARU, SPS
EuropeStar	100	140	12	2700	1630	/94 %	FM/2000	CCR, ARU, SPS, RC
GE-2A	70	2 x 120	12	4400	2300	/94 %	FM/2001	CCR, ARU, SPS, RC, DT
INSAT 3 C-band	26 to 43	63	4	2400	1600	/91 %	FM/2000	CCR, ARU, SPS, CPO
INSAT 3 S-band	26 to 43	70	2.5	2400	1600	/91 %	FM/2000	CCR, ARU, SPS, CPO
INSAT 3 Ku-band	26 to 43	70	12	–	1600	/91 %	FM/2000	CCR, ARU, SPS, CPO

* Remarks: CCR = Cathode Current Regulation, SPS = Secondary Power Supply, ARU = Automatic Restart Units, CPO = Critical Pressure Operation, HS = Heater Step, DT = Dual Tube Supply, RC = Radiation Cooled TWT, MPM = Microwave Power Module

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